ARS SPECIAL REPORT

Applied Mulches and Mulching

ARS 22-71

August 1961

Agricultural Research Service
UNITED STATES DEPARTMENT OF AGRICULTURE

FOREWORD

Many growers are interested in the possibilities of applied mulches for maintaining and improving soil conditions and increasing farming efficiency and crop yields. But despite the longtime use of mulches by gardeners and nurserymen--and to a lesser extent by farmers--mulch farming has not been extensively developed in the United States, and pertinent information about mulching is not readily available in all localities.

This report brings together information from various sources to help agricultural leaders answer questions of growers regarding mulching and the various mulches in the light of experiments and experience under conditions similar to those prevailing in their area.

The broad patterns of the general effects of mulching on crops and soils under varying conditions in this country are discussed in the first section of the report. The second section deals in more detail with particular types of mulches, their uses, and limitations.

Since up-to-date information on stubble mulching and crop residue management is already available in publications issued by the Agricultural Research Service of the U. S. Department of Agriculture and by the States, this report deals primarily with applied mulching. A list of publications dealing with various aspects of mulching is appended to this report.

Information in this report was provided by the Soil and Water Conservation Research Division of the Agricultural Research Service.

APPLIED MULCHES AND MULCHING

Use of mulches in the production of crops is an old practice, possibly dating back to the beginnings of agriculture. The value of applied mulches in reducing and slowing down runoff and soil erosion has been established by experience and research and is widely recognized. Substantial increases in certain crop yields have followed the use of mulch in some places and under some conditions. In other cases, however, a depressing effect on crop production has followed mulching.

Among the materials commonly used for mulching are: Crop residues; sawdust or woodchips; and manure. Paper, fine brush, or even stones are sometimes used for mulching. A relatively new development is the growing use of plastic mulches by gardeners and farmers.

To date, costs and limited supplies of commercial mulching materials have restricted the use of applied mulching largely to the production of relatively high-value crops, to special uses where the value of mulches for increasing production efficiency is well established, or to circumstances in which the need for mulching to conserve moisture or prevent erosion is acute. Cases in point are the use of mulches by truck farmers and nurserymen in the production of high-value vegetables and plants and the specialized use of sawdust mulch by berry growers to keep their fruit clean.

HOW MULCHES AFFECT SOIL CONDITIONS AND YIELDS

The fact that the effects of mulching are seldom simple has complicated the search for precise information. However, certain patterns of behavior of soils and plants under mulch have been observed in mulching studies conducted in this country and abroad.

Among the more important ways in which mulches may affect soil conditions are by: (1) Maintaining soil structures; (2) conserving moisture; (3) modifying temperature; (4) affecting available plant nutrients by changing the chemical content of the soil and increasing biological activity; and (5) inhibiting soil erosion due to wind or water.

Apparently temperature or moisture, or a combination of both, are most frequently the critical factors in determining whether use of a mulch will affect crop yields favorably or adversely.

Mulching Maintains Good Soil Structure

Mulches help maintain desirable soil structure and thereby aid in conserving soil and water and in providing a better soil environment for the plant.

Mulches protect the soil from the direct impact of rainfall. Raindrops fall with tremendous force. When this force strikes on bare ground, much of the energy is expended by breaking up soil aggregates and sealing and compacting the surface soil. This decreases the infiltration capacity of the soil and increases runoff and erosion. By breaking the force and size of the falling raindrops, surface mulches maintain soil porosity and conserve soil and water.

Mulches Conserve Moisture

One of the major reasons farmers use mulches is to make more efficient use of available moisture in producing crops. In most cases, the moisture content of the surface soil under mulch is higher than when soil is clean-cultivated.

Runoff Reduced

Mulches prevent crusting and reduce the amount of water that runs off the surface of the soil during rain by maintaining conditions favorable to the infiltration of water.

Results of early experiments by USDA scientists in Ohio indicated that the greater penetration of water generally occurring in mulched soils was primarily due to the protection that the cover affords to existing favorable soil structure.

When the soil was not permeable, putting mulch on the surface did not cause the water to penetrate. But after the soil had been cultivated 1-inch deep to break the surface crust, the infiltration rate under mulching after 60 minutes was 2.10 inches an hour as compared to 0.28 inches an hour on similar, unmulched plots. On the unmulched plots, the force of the rain produced a dense surface which at best was slowly permeable.

Evaporation Affected

Experiments in a number of States have shown the efficiency of mulch in holding down evaporation. Amount of moisture savings attributable to reduced evaporation under a straw mulch varied widely with climate and other varying test conditions. In experiments in Tennessee and Michigan, for example, indirect measurements showed that, in humid areas, evaporation losses may be reduced by the use of mulch. The reductions ranged from around 12 or 16 percent to as much as 50 percent or more.

Plastic sheeting used as a ground cover can prevent water from evaporating from the soil surface. When used on a dry surface soil, a plastic cover tends to increase the moisture at the surface. This results because water vapor from deep in the soil condenses on the film and drips back into the ground.

When used for water conservation purposes, the plastic sheeting is lapped or perforated in a way to admit rain but at the same time inhibit evaporation.

Because of the demonstrated moisture-saving effect of plastic sheeting, ARS researchers predict an increased use of this type of mulch cover for water-saving purposes if the shortage of water becomes more critical.

Weed Growth Affected

Mulching can conserve water for crops by reducing competition from weeds for available soil moisture.

Fine, close-grained mulches applied around growing crops tend to inhibit weed growth by excluding light which weeds require for growth. Unperforated black paper or plastic sheeting is very effective for this purpose. Loose, porous mulches will not give good weed control.

Yields Affected by Moisture

The moisture-conserving effect of mulching appears in many cases to be the critical factor determining whether or not the practice increases crop yields.

Experiments in North Carolina, for example, showed that wheat straw mulch at 3 tons per acre increased moisture in the soil and markedly increased corn yields during drought conditions. Increases averaged 21 bushels per acre in 8 experiments, with a close ratio between corn yields and moisture content of the soil. In 10 experiments conducted under good moisture conditions, mulching did not greatly affect yields.

Similarly with tobacco, there is a close correlation between drought conditions and the effect of mulching on crop yields. ARS investigators working in Maryland found that tobacco grown under 4 to 6 tons of straw mulch per acre gave yields as good as those from cultivated fields during 5 years when rain was normal or less than normal--but crop values were reduced during 2 years of above normal rainfall.

On land where excess moisture is a problem because of poor drainage and heavy rainfall, mulching could obviously have an adverse effect.

Mulching Affects Temperature

Mulches--other than plastics or paper--generally reduce temperature variations in the soil beneath them. Temperature effects of mulching are not always favorable to efficient crop production, however. In cool areas of the country, the generally lower temperatures of soil under mulch during the spring growing season frequently have an inhibiting effect on growth of crops such as corn. To use mulch effectively for temperature control or to avoid adverse effects on soil temperature as related to crop production, farmers need to know how hot- and cold-weather conditions influence the effect of the mulch on soil temperature.

In experiments in the Eastern United States using up to 2 tons of straw per acre in growing winter wheat, investigators found that although mulch reduces winter injury from heaving when and where it occurs it tends to reduce yields in years when freezing is not a problem. Among the adverse effects that can result from mulching shown by the wheat studies are that the mulch may be a source of insect pests and may reduce the supply of available nitrogen in the soil.

Mulching may, under some circumstances, increase the frost hazard in orchards or similar perennial plantings. For example, mulch or cover crops in peach orchards may increase the danger of frost damage to peach blossoms, especially where the air drainage is poor.

During cold weather, heat absorbed by the soil in the daytime is radiated at night, warming the surrounding air. Since mulching generally reduces the amount of heat absorbed by the soil, it will under such circumstances reduce the amount of radiation given off at night. As a result, mulching may sometimes reduce the temperature of the surrounding air to a dangerous degree. This is more likely to occur on low-lying land due to poor air drainage.

Data from numerous studies of the effect of mulch on corn yields in cool sections of the country suggest that generally low temperatures under mulches retard the growth of the corn plant during the early part of the season. In some cases the beneficial effects of mulching during summer can, however, compensate for the retarding effect of reduced temperatures on early corn growth.

In experiments using mulches on vegetables, researchers of the Pennsylvania State Agricultural Experiment Station concluded that reduced temperatures under mulches in the early spring might partly explain smaller early yields and greater total yields in midsummer when lower soil temperatures would have a favorable result.

The precise effect of mulching on soil temperatures and indirectly on plant growth is determined by a combination of factors.

Color of the mulch is one of the factors influencing soil temperature. Light-colored materials tend to reflect heat rays while dark-colored mulches tend to absorb them.

This was brought out in a Kansas study which showed that the darkening of a straw mulch by humification influenced the effect the mulch had on the soil's summer temperature. Under a light-colored, fresh mulch the soil temperature was 2.8° C. lower than in bare soil, while soil under a dark gray, partially decomposed mulch was only 0.2° C. lower than bare soil. Reflection from the fresh, light-colored mulch was about three times as great as from the dark, partially decomposed mulch: 32 candles of light per square foot as compared to 11 candles.

The color is particularly important when plastic materials or paper are used for mulching. The amount of solar energy transmitted to the soil as light or heat varies widely with the color and transparency of the plastic. Also, as compared to decomposible mulches which darken quickly, the plastic retains its original color longer.

Soil temperature is usually highest under a cover of clear plastic which permits the heat rays to pass through the film. When black plastic sheeting is used, the plastic itself may become extremely warm--150° F. or more on a hot summer day--but the effect on soil temperature will vary according to placement. If the black plastic is in contact with the ground, most of the heat will be absorbed by the soil. But if the black plastic is supported above ground with an insulating air layer beneath, the surface soil may be only a little, if any, warmer than similar soil exposed to direct sunlight. For keeping the soil cool, a cover characterized by high reflection and low transmission of light--such as aluminum foil

and white, partially opaque plastic sheeting--is most effective. At present, however, only clear and black plastic are generally available to growers through regular channels--and opaque and colored plastic now used only on an experimental scale.

Mulches Affect the Availability of Plant Nutrients

Chemical Effects

One way mulching affects nutrient properties of the soil is through changes in its chemical composition. Like other effects of mulching, its chemical effects are complex, resulting as they do from a number of factors and interacting with varying environmental and other conditions--kind of mulching material used, soil fertility, temperature, moisture and biological activity in the soil, among others. Consequently, the chemical effect of surface mulch may--depending on the circumstances--have either a beneficial or depressing effect on plant growth and yield.

Kind of mulch is a factor influencing the effect of mulching on chemical properties of the soil.

Plant residue mulches contain varying amounts of minerals which plants require for growth--nitrogen, potassium, phosphorus, calcium, and sulfur. Use of such mulches may increase the amount of these minerals available in the soil as plant food directly through the simple process of leaching. Most of the potassium is readily leached from plant residues by rainfall, for example. However, much of the mineral content of plant residues is not immediately available as plant nutrients: only becomes so when released through the process of decomposition. Availability of nitrogen and phosphorus, for example, is largely dependent on decomposition. The process of decomposition, in turn, is closely related to biological activity in the soil.

Effect on Biological Activities

Generally the use of mulches promotes biological activity by helping create temperature and moisture conditions favorable to growth and activity of soil organisms. In areas where temperature and moisture conditions are favorable for high level activity of soil organisms (in the humid South, for example), the rate of decomposition of organic mulches is likely to be faster than in northern or arid sections. While such an acceleration in the decomposition process speeds release of plant nutrients, the speedup in humification leaves the soil with an adequate protective cover for a shorter period of time.

Substantial amounts of nitrogen are required for decomposing plant residues. When an organic mulching material does not contain all the nitrogen required for decomposition, the mulch tends to "borrow" nitrogen from the soil or fertilizer applied to the soil--so leaves less nitrogen available for plant growth during the decomposition process. Consequently, signs of nitrogen deficiency are frequently observed in plants grown under heavy mulches, unless sufficient nitrogen fertilizer is added to compensate for the soil or fertilizer nitrogen required in the decomposition process. The amount of additional nitrogen fertilizer needed to compensate for the nitrogen tieup varies with the type of mulch and its state of decomposition.

Duration and severity of the nitrogen depression sometimes observed following application of organic mulches is affected by a number of factors in addition to the kind of mulching material used and its nitrogen content. Soil fertility--particularly the amount of nitrogen in the soil--is a significant factor in determining whether or not crop yields will be affected adversely under mulching. This is illustrated by studies of wheat grown in various sections of the West. Although yields grown under a system of mulch farming tended to be less than under moldboard plowing in most areas studied, no depressing effect on grain yields was observed in areas where the nitrate content of the soil was high.

Increases in the amount of soil nitrate following application of mulch occur under some conditions. In fact, such an increase has been reported in the majority of studies in which "inert" mulches such as plastic were used.

When decomposable mulches such as straw or hay or manure are used, the rate of decomposition and the proportion of carbon to nitrogen are significant factors in determining whether mulching will increase or decrease the nitrate content of the soil.

More extensive root systems often developing in the soil layer immediately under a mulch may contribute to the improved utilization of plant nutrients frequently observed after the application of organic mulches. At the Pennsylvania State Agricultural Experiment Station, researchers growing vegetables under mulch and clean cultivation found substantial yield increases in mulched vegetables and observed that plant roots grew profusely in the surface layers of the soil and in the mulch itself. The investigators thought that this increase in the growth of surface roots under mulches might in part explain the increased yields--since the additional root growth gave the mulched plants contact with an additional volume of soil from which to absorb nutrients.

Erosion Reduced by Mulching

The value of mulches in controlling erosion is widely recognized.

Earlier sections of this report have incidentally explained some of the more important ways in which mulching inhibits erosion: By reducing runoff; by protecting the soil from sealing action of raindrops and maintaining its permeability; and by providing conditions favorable to increased activity of organisms which can result in more stable soil aggregates.

Extent of the soil-saving effect of mulches has been measured in numerous studies. In Illinois tests, for example, soil losses after an hour's rain of 1-3/4 inches were 3,225 pounds per acre from bare ground as compared to 205 pounds from ground mulched with cornstalks.

In studies recently conducted in cooperation with the Georgia Agricultural Experiment Station, ARS scientists found that a mulch of pine needles, straw, or any other cheap mulching material applied at the rate of around 2 tons per acre could be used successfully to prevent erosion on steep road banks until a cover of vegetation could be established.

Recent experiments in Kansas have shown that the efficiency of hay mulch for protecting grass seedings from wind erosion can be increased by anchoring the hay with either smooth or cutaway disks. On slopes too steep for the disks, a spray application of rapid curing liquid asphalt accomplished the same purpose.

Mulches Sometimes Used to Keep Crops Clean

Suitable mulching materials--such as sawdust--are sometimes used by growers to keep low-growing fruits or vegetables clean.

TYPES OF MULCHING MATERIALS

Some mulching materials--including crop residues, sawdust and other wood-wastes, manure, and plastic sheeting--how they are used, their advantages, and limitations, are discussed in the following sections.

Crop Residues A Major Source of Mulching Materials

The trend to make maximum use of plant residues results from the need to conserve water, prevent erosion, and maintain soil fertility. Development and use of machinery, chemical weedkillers, and fertilizers designed to help overcome tillage and yield problems associated with the use of plant-residues in crop production have helped make increased use of the practice feasible.

When crop residues are used as mulches they perform the double function of returning plant nutrients and organic matter to the soil and providing a protective cover.

Since availability is a limiting factor in the use of mulches the amount of residues normally left over from various crops as well as their nutrient content is significant to farmers planning to use them. Under normal conditions properly fertilized crops will yield 2 tons or more of dry crop residues per acre in addition to good crop yields.

The quantity of nutrients, especially nitrogen, in the mulch affects the amount of nitrogen and other fertilizer that may be required to supplement the mulch in order to avoid a yield reduction because of a temporary tieup of soil nitrogen. For example, a ton of wheat straw contains only 14 pounds of nitrogen but soil micro-organisms would require 30 pounds of nitrogen to sustain them during the decomposition process. If 2 tons of wheat straw were used on an acre of land, then a maximum of 32 extra pounds of nitrogen fertilizer would be needed in addition to that required for growing the crop.

When crops containing more than 30 pounds of nitrogen per ton are used for mulching, the "extra" nitrogen will be released for plant use. Thus a crop requiring 100 pounds of nitrogen fertilizer per acre without mulch would need only 82 pounds of fertilizer if grown under a residue mulch containing 48 pounds of nitrogen--18 "extra" pounds above the 30 pounds required for decomposition.

A large part of the nitrogen and other plant nutrients contained in crop-residue mulches eventually makes its way back into the soil through leaching and decomposition. Hence the nutrient content of the various plant residues is important as a measure of its longterm contribution to soil fertility as well as because of its immediate implications regarding nitrogen availability and fertilizer requirements.

Ranges in the nutrient content per ton of the various types of plant residues frequently used for mulches are given in table 1.

TABLE 1.--Nutrient Content Per Ton of Various Types of Plant Residues[1] Frequently Used for Mulching.

Type of Crop	Range of Elements Contained per Ton		
	Nitrogen (N)	Phosphorus (P_2O_5)	Potash (K_2O)
	Pounds	*Pounds*	*Pounds*
Grain straw	10 - 14	3 - 5	15 - 30
Grass residues	16 - 60	3 - 10	20 - 60
Legume residues	40 - 60	3 - 10	20 - 60
Corn fodder	10 - 20	5 - 10	20 - 30

[1] In addition to plant type, many factors--including maturity of the plant, soil, fertility, and weather--affect the nutrient content of crops.

Sawdust and Other Wood Wastes

Sawdust, wood chips, and shavings constitute an abundant source of mulching material in many areas of the country.

Wood-waste mulches provide a protective cover and contribute organic matter to the soil but do not contain as high a proportion of nitrogen and other essential plant nutrients per ton of dry matter as do residues of most general farm crops. For example, a ton of dry sawdust contains on the average about 4 pounds of nitrogen, as compared to 14 pounds of nitrogen in a ton of wheat straw.

To avoid a temporary nitrogen deficiency in using sawdust or other wood-waste mulches, the addition of more supplementary nitrogen to meet the needs of decay micro-organisms is therefore required than is the case with most general crop residues. The supplementary nitrogen needed to make up the nitrogen deficiency in sawdust amounts to about 24 pounds of nitrogen per ton of dry sawdust. Table 2 gives the amount of commonly used fertilizer material required to counteract the nitrogen-depleting effect of a ton or bushel of fresh, dry sawdust.

TABLE 2.--Approximate Quantity of Various Nitrogen Fertilizers Required to Counteract the Nitrogen-Depleting Effect of a Ton or Bushel of Average Fresh, Dry Sawdust

Nitrogen source	Nitrogen Content	Quantity required	
		Per ton	Per bu.[1]
	Percent	*Pounds*	*Pounds*
Ammonium sulfate	21.0	115	1.2
Ammonium nitrate	33.5	72	.8
Sodium nitrate	16.0	150	1.6
10-6-4 fertilizer	10.0	240	2.7
5-10-5 fertilizer	5.0	480	5.0

[1] Estimated on the basis that a bushel of dry sawdust weighs 24 pounds.

Because sawdust decomposes slowly, it is advisable to apply the supplementary nitrogen in two or more applications. If applied all in one application, the nitrogen may be leached away or absorbed by plants leaving insufficient nitrogen to feed the soil micro-organisms.

Since decay bacteria also require phosphorus in excess of that contained in ordinary sawdust, researchers feel that temporary phosphorus deficiencies frequently occur following use of sawdust mulches, although the effects are not so striking as the results of nitrogen shortage. As in the case of nitrogen deficiency, any phosphorus depression accompanying sawdust mulches is temporary and can be avoided by the use of fertilizer.

Yield depressions which generally follow applications of sawdust unaccompanied by supplementary nitrogen have caused some observers to suspect that wood wastes contain toxic materials. Recent studies show, however, that, except in a few rare cases, wood-waste mulches are not toxic in their effect on plants when used in usual quantities and with supplementary nitrogen. In the exceptional cases when a particular type of sawdust would have a toxic effect if used fresh, this can be counteracted by weathering the sawdust in advance of application or putting it on the soil 2 or more months before planting. A longer period of weathering is required if the sawdust is applied during the cold months when activities of decay organisms are slowed down.

Wood Chips Similar in Effect to Sawdust

Although not so widely used for mulching as sawdust, wood chips provide many of the same benefits and are being increasingly used. Like sawdust in chemical composition, wood chips, however, decompose more slowly.

Slow decomposition rate means that the nitrogen tieup will continue over a longer period of time but peak requirements will be less with a wood-chip mulch. Slow decomposition also means that the protective value of the mulch will continue longer--since decomposition reduces the bulk of the mulching material.

Protective Value of Manure Mulch Important

The protective value of manure used as a mulch is frequently greater than its value as a source of plant foods.

In USDA experiments in Ohio, corn yields were larger under a top dressing of strawy manure applied after the first cultivation than when the manure was plowed under. Yield differences in favor of the manure-mulched corn were greater in dry years, suggesting that the difference was partly due to the moisture-conserving effect of the manure mulch.

In another Ohio experiment, ARS and State investigators found that manure mulching reduced erosion on 10 and 12 percent slopes to 0.5 tons per acre as compared to 12.2 tons per acre on unmulched land.

Manure mulch has also been found to reduce soil blowing of sandy soil and to be especially valuable for protecting newly seeded crops from wind and rain. When a critical problem of wind or water erosion exists and manure is the only available mulching material, it is therefore advisable to give first priority to its use as a mulch--as for example, to provide a protective cover for newly seeded waterways.

Since stable manure usually contains considerable excess of nitrogen over that required for decomposition, the problem of a temporary tieup of soil nitrogen is not involved in its use. But because of the limited supplies of nutrients it contains as compared to mineral fertilizers, manure mulch is NOT a fertilizer substitute but rather a supplementary source of plant foods.

Plastic Ground Covers, A Relatively New Development

Use of plastic materials as a ground cover is a relatively recent development which has opened up new possibilities to growers for increasing crop production efficiency by promoting favorable moisture and temperature conditions and maintaining soil-tilth in their fields and gardens.

Unlike other mulches, plastic ground covers are "inert": They will not add plant nutrients to the soil by leaching or decomposition. But plastic ground covers have been successfully used to achieve a number of effects, sometimes with certain advantages over other mulches. However, cost and the difficulty of anchoring the cover securely have thus far generally limited the use of plastic cover to a few specialized uses or to small plots.

Among the special effects for which plastic ground cover has been used successfully are: (1) To warm soils; (2) to control weeds; (3) to reduce evaporation; and (4) to aid seed germination by keeping the surface soil moist.

Because light is needed for plant growth, black plastic is a good choice for controlling weeds. By the same token, clear plastic is suitable for cold frames and hotbeds, particularly in cold weather when the soil needs warming. In using clear plastic, however, care must be taken to prevent a buildup of damaging temperatures on unseasonably warm, sunny days.

MANY MULCHING UNKNOWNS

Despite steady progress in mulch research, many perplexing questions remain unanswered and some once widely accepted theories have been brought into question by conflicting evidence. For example, it was once generally accepted as a fact that mulching greatly improved soil structure. But, as previously noted, present evidence indicates that the beneficial effect of mulching on soil structure is largely protective. Similarly, although it was once assumed that covering the ground with sawdust would result in low pH value needed by acid-requiring plants, research studies have revealed that this is not universally the case. Not only is there considerable variation in the pH value of fresh sawdust from different woods, but decomposition tends to break down any acids contained rather quickly, and the end result from the decomposition of most wood residues is probably slightly basic.

MULCHING PROSPECTS

Mulches serve important functions. However, despite the widespread interest of farmers in the soil-conserving and other beneficial effects of mulching, the practice is largely undeveloped in many areas because of the still unsolved problems encountered in using the various mulches under some conditions. The difficulties involved in using plant-residue mulches in cool, humid areas, are an example.

The increasing demand for water associated with the steady growth in population and the encroachment of the suburbs on farm land underline the need for developing more effective techniques for efficient use of soil and water resources. As one of the promising cultural practices which help maintain soil fertility and tilth, mulching is now the focus of considerable research and is likely to continue so.

Research and experience have already yielded considerable information to help growers make more effective use of mulches. The use of mineral nitrogen with organic mulches to avoid temporary nitrogen depression and the development of data showing the additional nitrogen required by the various organic mulches to support decay organisms are examples of research-developed improvements in the use of applied mulches.

Research is continuing, with the possibilities of new mulching materials and greater precision in the use of old mulches under scrutiny. As ways are discovered to use mulches efficiently in areas and with crops where they now result in reduced yields or are too costly, their use will increase.

SOME MULCHING REFERENCES

This report on mulching and mulches has been largely confined to broad, general principles. More detailed information on special mulching techniques, machinery, and procedures and on mulching materials is available in other publications. A few publications dealing with various aspects of mulching are listed below:

A Summary of Research Experiences With Stubble-Mulch Farming In the Western States--By A. W. Zingg and C. J. Whitefield.--U. S. Dept. Agr. Tech. Bull. No. 1166, October 1957. (USDA in cooperation with State Agricultural Experiment Stations)

Surface Mulches and Mulch Tillage for Corn Production--By H. L. Borst and H. J. Mederski. Ohio Agr. Expt. Sta. Res. Bull. 796. November 1957. (ARS, USDA, cooperating)

The Use of Sawdust for Mulches and Soil Improvement--By F. E. Allison and M. S. Anderson. U. S. Dept. Agr. Circular No. 891, November 1951.

Mulching--By G. V. Jacks, W. D. Brind, and Robert Smith. Technical Communication No. 49 of the Commonwealth Bureau of Soil Science, Commonwealth Agricultural Bureaux, Farnham Royal, Bucks, England. 1955.

Polythene Film in Horticulture--By H. R. Spices. Faber and Faber, 24 Russell Sq., London. 1959.

Using Crop Residues on Soils of the Humid Area--By W. E. Larson and O. W. Beale. U. S. Dept. Agr. Farmers' Bull. 2155, March 1961. (ARS, USDA in cooperation with the Iowa and South Carolina Experiment Stations)

☆ U.S. GOVERNMENT PRINTING OFFICE : 1961 O - 605337

Growth Through Agricultural Progress